

Analysis of the charmed mesons $D_1^*(2680)$, $D_3^*(2760)$ and $D_2^*(3000)$

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In this work, we systematically study the strong decay behavior of the charmed mesons $D_1^*(2680)$, $D_3^*(2760)$ and $D_2^*(3000)$ reported by the LHCb collaboration. By comparing the masses and the decay properties with the results of the experiment, we assign these newly observed mesons as the $2S\frac{1}{2}1^-$, $1D\frac{5}{2}3^-$ and $1F\frac{5}{2}2^+$ states respectively. As a byproduct, we also study the strong decays of the unobserved $2P\frac{3}{2}2^+$, $2F\frac{5}{2}2^+$ and $3P\frac{3}{2}2^+$ charmed mesons, which is useful for future experiments in searching for these charmed mesons.

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1 Introduction

Recently, the LHCb Collaboration studied the resonant substructures of $B^- \rightarrow D^+ \pi^- \pi^-$ decays in a data sample corresponding to 3.0 fb^{-1} of pp collision data recorded by the LHCb experiment during 2011 and 2012. By a Dalitz plot analysis technique, the presence of resonances with spins 1, 2 and 3 at the $D^+ \pi^-$ mass spectrum were confirmed [1]. Their analysis indicated that these resonances are mainly from the contributions of $D_2^*(2460)$, $D_1^*(2680)$, $D_3^*(2760)$ and $D_2^*(3000)$ charmed mesons. The masses and decay widths of these mesons are

$$D_2^*(2460) : M = 2463.7 \pm 0.4 \pm 0.4 \pm 0.6 \text{ MeV}, \Gamma = 47.0 \pm 0.8 \pm 0.9 \pm 0.3 \text{ MeV}$$

$$D_1^*(2680) : M = 2681.1 \pm 5.6 \pm 4.9 \pm 13.1 \text{ MeV}, \Gamma = 186.7 \pm 8.5 \pm 8.6 \pm 8.2 \text{ MeV}$$

$$D_3^*(2760) : M = 2775.5 \pm 4.5 \pm 4.5 \pm 4.7 \text{ MeV}, \Gamma = 95.3 \pm 9.6 \pm 7.9 \pm 33.1 \text{ MeV}$$

$$D_2^*(3000) : M = 3214 \pm 29 \pm 33 \pm 36 \text{ MeV}, \Gamma = 186 \pm 38 \pm 34 \pm 63 \text{ MeV}$$

Actually, people have found many other charmed mesons before these discoveries [2–9], which have greatly enriched the charmonium spectra. On the other hand, these discoveries also shed more light on our knowledge about the essence of the elementary particles in the micro-world. For $D_2^*(2460)$ as an example, it has been well established previously and the $1P\frac{3}{2}2^+$ assignment is strongly favored [10]. We studied the nature of the states $D_1^*(2680)$, $D_3^*(2760)$ and $D_2^*(3000)$ in our previous work using

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the heavy meson effective theory [11]. Some of the strong decay behavior have also been studied in which the calculated ratios among the decay widths can be used to confirm or reject the assignments of the newly observed charmed mesons. The decay behavior of the $D_2^*(3000)$ charmed meson was also analyzed in reference [12], where it was assigned as the 2^3F_2 or 3^3P_2 states. In order to identify the $D_1^*(2680)$, $D_3^*(2760)$ and $D_2^*(3000)$ and give more specific decay widths and the ratios, we further analyze the strong decay properties of these newly observed charmed mesons using the 3P_0 decay model.

The 3P_0 decay model is known as quark pair creation model (QPC) which was firstly introduced by Micu [13] in 1969. An important feature of the this decay model, apart from its simplicity, is that it provides the gross features of several transitions with two parameters, the pair-creation strength γ and the oscillator parameter R , which can be fitted to the experimental data. Soon after the introduction of the 3P_0 model, it was further developed by other collaborations [14, 15]. This model, extensively applied to the decays of light mesons and baryons [16–25], has been applied to evaluate the strong decays of heavy meson in the charmonium [26–28], bottomonium [28, 29], and open-charm sectors [30, 31].

Just as what we have analyzed [11], the mesons of $D_1^*(2680)$, $D^*(2600)$ and $D_J^*(2650)$ have the similar mass and width [32, 33], and can be assigned to be the same states $2S\frac{1}{2}1^-$ [34–38]. Based on the same analysis, $D_3^*(2760)^0$, $D^*(2760)^0$, $D_J^*(2760)^0$ may be the same particle, and can be assigned to be the $1D\frac{5}{2}3^-$ state [32–40]. As for $D_2^*(3000)$, it can be a P wave and F wave charmed meson. Its mass can be calculated by different theoretical models, such as the relativized quark model based on a universal one-gluon exchange plus linear confinement potential [41], the relativistic quark model includes the leading order $1/M_h$ corrections [42], the QCD-motivated relativistic quark model based on the quasipotential approach [43]. According to these calculations, $1F\frac{5}{2}2^+$, $2P\frac{3}{2}2^+$, $2F\frac{5}{2}2^+$ and $3P\frac{3}{2}2^+$ can also be assigned as the candidates of the possible states of the charmed meson $D_2^*(3000)$.

To further verify the states of $D_1^*(2680)$ and $D_3^*(2760)$ and check the possibilities of different assignments of the $D_2^*(3000)$, we give a systematic analysis of the decay behaviors about these charmed mesons. The article is arranged as follows: In section 2, the brief review of the 3P_0 decay model is given (For the detailed review see Refs. [15, 17, 18, 20]); in Sec.3, we study the strong decays of the charmed mesons $D_1^*(2680)$, $D_3^*(2760)$ and $D_2^*(3000)$ observed by the LHCb collaboration with the 3P_0 decay model; in Sec.4, we present our conclusions.

2 METHOD

2.1 The decay model

The 3P_0 decay model assumes that a quark-antiquark pair is created from the vacuum with the corresponding quantum number 0^{++} . This new $q\bar{q}$ together with the $q\bar{q}$ within the initial meson regroups into two outgoing mesons in all possible arrangements for the meson decay process $A \rightarrow BC$

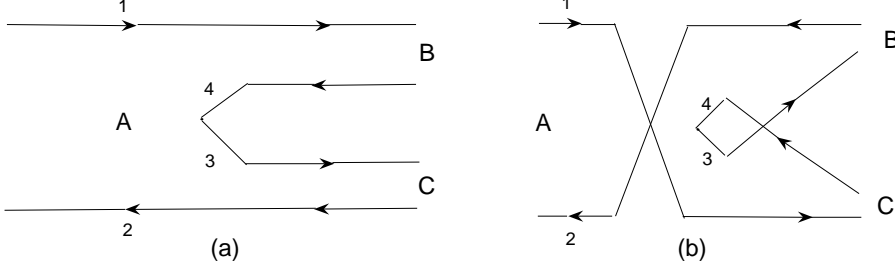


FIG. 1: The two possible decay processes of $A \rightarrow BC$ in the 3P_0 model.

as shown in Fig. 1.

In the nonrelativistic limit, the transition operator of this process can be expressed as

$$T = -3\gamma \sum_m \langle 1m1-m | 00 \rangle \int d^3\vec{p}_3 d^3\vec{p}_4 \delta^3(\vec{p}_3 + \vec{p}_4) \mathcal{Y}_1^m\left(\frac{\vec{p}_3 - \vec{p}_4}{2}\right) \chi_{1-m}^{34} \varphi_0^{34} \omega_0^{34} b_3^\dagger(\vec{p}_3) d_4^\dagger(\vec{p}_4) \quad (1)$$

where the dimensionless parameter γ denotes the creation strength of the quark-antiquark $q_3\bar{q}_4$ pair. \vec{p}_3 and \vec{p}_4 are the momenta of this quark-antiquark pair. Its flavor, color, and spin wave functions are represented by φ_0^{34} , ω_0^{34} , and χ_{1-m}^{34} , respectively. $\mathcal{Y}_1^m(\vec{p}) \equiv |\vec{p}| Y_1^m(\theta_p, \phi_p)$ is a solid harmonic polynomial corresponding to the p-wave quark pair.

In the center of mass frame of parent meson A , the helicity amplitude $\mathcal{M}^{M_{J_A} M_{J_B} M_{J_C}}$ of the decay process $A \rightarrow BC$ is written as

$$\begin{aligned} \mathcal{M}^{M_{J_A} M_{J_B} M_{J_C}}(\vec{P}) = & \gamma \sqrt{8E_A E_B E_C} \sum_{\substack{M_{L_A}, M_{S_A}, \\ M_{L_B}, M_{S_B}, \\ M_{L_C}, M_{S_C}, m}} \langle L_A M_{L_A} S_A M_{S_A} | J_A M_{J_A} \rangle \langle L_B M_{L_B} S_B M_{S_B} | J_B M_{J_B} \rangle \\ & \times \langle L_C M_{L_C} S_C M_{S_C} | J_C M_{J_C} \rangle \langle 1m1-m | 00 \rangle \langle \chi_{S_B M_{S_B}}^{14} \chi_{S_C M_{S_C}}^{32} | \chi_{S_A M_{S_A}}^{12} \chi_{1-m}^{34} \rangle \\ & \times [\langle \phi_B^{14} \phi_C^{32} | \phi_A^{12} \phi_0^{34} \rangle I(\vec{P}, m_1, m_2, m_3) \\ & + (-1)^{1+S_A+S_B+S_C} \langle \phi_B^{32} \phi_C^{14} | \phi_A^{12} \phi_0^{34} \rangle I(-\vec{P}, m_2, m_1, m_3)] \end{aligned} \quad (2)$$

where the spatial integral is defined as

$$\begin{aligned} I(\vec{P}, m_1, m_2, m_3) = & \int d^3\vec{p} \psi_{n_B L_B M_{L_B}}^* \left(\frac{m_3}{m_1 + m_2} \vec{P}_B + \vec{p} \right) \psi_{n_C L_C M_{L_C}}^* \left(\frac{m_3}{m_2 + m_3} \vec{P}_B + \vec{p} \right) \\ & \times \psi_{n_A L_A M_{L_A}}(\vec{P}_B + \vec{p}) \mathcal{Y}_1^m(\vec{p}) \end{aligned} \quad (3)$$

where $\vec{P} = \vec{P}_B = -\vec{P}_C, \vec{p} = \vec{p}_3$, m_3 is the mass of the created quark q_3 , the simple harmonic oscillator (SHO) approximation is used for the meson space wave functions:

$$\Psi_{nLM_L}(\vec{p}) = (-1)^n (-i)^L R^{L+\frac{3}{2}} \sqrt{\frac{2n!}{\Gamma(n+L+\frac{3}{2})}} \exp\left(-\frac{R^2 p^2}{2}\right) L_n^{L+\frac{1}{2}}(R^2 p^2) \mathcal{Y}_{LM_L}(\vec{p}) \quad (4)$$

The partial wave amplitudes are related to the helicity amplitudes by [45]

$$\mathcal{M}^{JL}(\vec{P}) = \frac{\sqrt{4\pi(2L+1)}}{2J_A+1} \sum_{M_{J_B} M_{J_C}} \langle L0JM_{J_A} | J_A M_{J_A} \rangle \langle J_B M_{J_B} J_C M_{J_C} | J M_{J_A} \rangle \mathcal{M}^{M_{J_A} M_{J_B} M_{J_C}}(\vec{P}) \quad (5)$$

where $M_{J_A} = M_{J_B} + M_{J_C}$, $\mathbf{J}_A = \mathbf{J}_B + \mathbf{J}_C$ and $\mathbf{J}_A + \mathbf{J}_P = \mathbf{J}_B + \mathbf{J}_C + \mathbf{J}_L$. The transition in terms of partial wave amplitudes is

$$\Gamma = \frac{\pi}{4} \frac{|\vec{P}|}{M_A^2} \sum_{JL} |\mathcal{M}^{JL}|^2 \quad (6)$$

where $P = |\vec{P}| = \frac{\sqrt{[M_A^2 - (M_B + M_C)^2][M_A^2 - (M_B - M_C)^2]}}{2M_A}$, M_A , M_B , and M_C are the masses of the meson A , B , and C .

2.2 Mixed states

Heavy-light mesons are not charge conjugation eigenstates and so mixing can occur among states with the same J^P that are forbidden for neutral states [46]. These occur between states with $J = L$ and $S = 1$ or 0 [46, 47]. When $J = L = 1$, the corresponding mixture angle is $\theta = -54.7^\circ$ or $\theta = 35.3^\circ$ [46, 47]. The two 1^+ charmed mesons are the mixtures of the 3P_1 and 1P_1 states:

$$\begin{pmatrix} |\frac{1}{2}, 1^+ \rangle \\ |\frac{3}{2}, 1^+ \rangle \end{pmatrix} = \begin{pmatrix} \cos \theta & -\sin \theta \\ \sin \theta & \cos \theta \end{pmatrix} \begin{pmatrix} |^3P_1 \rangle \\ |^1P_1 \rangle \end{pmatrix} \quad (7)$$

In our calculation, the final states are related to $D(2420)/D(2430)$ and $D_{s_1}(2460)/D_{s_1}(2536)$, which are the 1^+ states in the D and D_s meson families, respectively. $D(2420)/D(2430)$ and $D_{s_1}(2460)/D_{s_1}(2536)$ are the mixing of the 3P_1 and 1P_1 states, which satisfy the above relation (see Eq.7). Thus the helicity amplitude can also be deduced as follows

$$\begin{pmatrix} \mathcal{M}_{|A\rangle \rightarrow \frac{1}{2}, 1^+ C}^{JL} \\ \mathcal{M}_{|A\rangle \rightarrow \frac{3}{2}, 1^+ C}^{JL} \end{pmatrix} = \begin{pmatrix} \cos \theta & -\sin \theta \\ \sin \theta & \cos \theta \end{pmatrix} \begin{pmatrix} \mathcal{M}_{|A\rangle \rightarrow ^3P_1 C}^{JL} \\ \mathcal{M}_{|A\rangle \rightarrow ^1P_1 C}^{JL} \end{pmatrix} \quad (8)$$

and the decay width can be expressed as

$$\begin{aligned} \Gamma(|A\rangle \rightarrow \frac{1}{2}, 1^+ C) &= \sum_{JL} |\cos \theta \mathcal{M}_{|A\rangle \rightarrow ^3P_1 C}^{JL} - \sin \theta \mathcal{M}_{|A\rangle \rightarrow ^1P_1 C}^{JL}|^2 \\ \Gamma(|A\rangle \rightarrow \frac{3}{2}, 1^+ C) &= \sum_{JL} |\sin \theta \mathcal{M}_{|A\rangle \rightarrow ^3P_1 C}^{JL} + \cos \theta \mathcal{M}_{|A\rangle \rightarrow ^1P_1 C}^{JL}|^2 \end{aligned} \quad (9)$$

3 Numerical Results

The input parameters in the 3P_0 model mainly include the light quark pair($q\bar{q}$) creation strength γ , the SHO wave function scale parameter R , and the masses of the mesons and the constituent quarks. The adopted masses of the mesons are listed in TABLE I, and $m_u = m_d = 0.22$ GeV, $m_s = 0.419$ GeV and $m_c = 1.65$ GeV [48].

TABLE I: The adopted masses of the mesons used in our calculation.

States	M_{π^+}	M_{π^0}	M_{K^+}	M_{K^*}	M_η	$M_{\eta'}$	M_{D^+}	M_{D^0}
Mass(MeV)	139.57	134.9766	493.677	891.66	547.853	957.78	1869.6	1864.83
States	$M_{D_s^{*+}}$	$M_{D_s^+}$	$M_{D_0^*}(2400)$	$M_{D(2430)}$	$M_{D(2420)}$	$M_{D_{s0}^{*\pm}(2317)}$	M_ρ	M_ω
Mass(MeV)	2112.3	1968.47	2318	2427	2421.3	2317.8	770	782
States	$M_{D^{*+}}$	$M_{D^{*0}}$	$M_{D_2^*}(2460)$	$M_{D_{s1}}(2460)$	$M_{D_{s1}}(2536)$			
Mass(MeV)	2010.25	2006.96	2464.4	2459.5	2535.11			

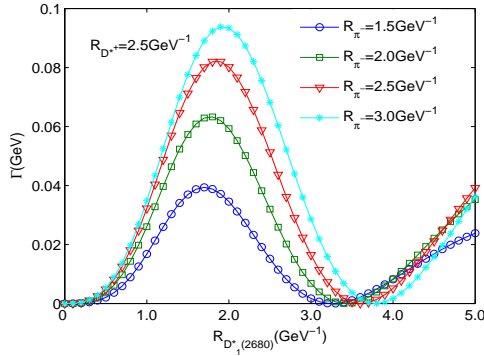


FIG. 2: The strong decay of $D_1^*(2680) \rightarrow D^{*+}\pi^-$ with $R_{D^{*+}} = 2.5$ GeV $^{-1}$.

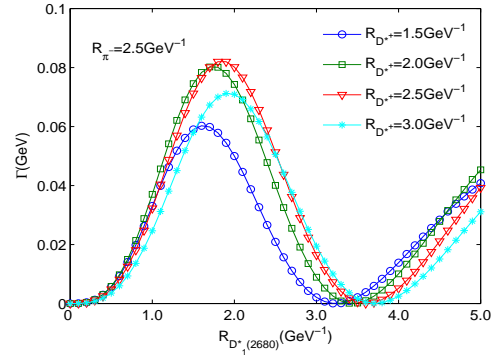


FIG. 3: The strong decay of $D_1^*(2680) \rightarrow D^{*+}\pi^-$ with $R_{\pi^-} = 2.5$ GeV $^{-1}$.

The scale parameter R has a significant influence on the shapes of the radial wave functions. The spatial integral in Eq.3 is sensitive to the parameter R , therefore the decay width based on the 3P_0 model is sensitive to the parameter R . Taking the decay $D_1^*(2680) \rightarrow D^{*+}\pi^-$ as an example, we plot the decay width versus the input parameter R in Figs. 2 and 3. From these two figures, we can easily see the dependence of the decay width on the input parameter R . If $R_{D^{*+}}$ and R_{π^-} are all fixed to be 2.5 GeV $^{-1}$ (the lines with triangles in Figs. 2 and 3), the decay width of the $D_1^*(2680)$ changes several times with the value of $R_{D^{*+}(2680)}$ from 1.5 GeV $^{-1}$ to 3.0 GeV $^{-1}$. Similarly, the decay width changes 2 – 3 times, when $R_{D_1^*(2680)}$ and R_{π^-} (or $R_{D_1^*(2680)}$ and $R_{D^{*+}}$) are fixed to be 2.5 GeV $^{-1}$ while the value of $R_{D^{*+}}$ (or R_{π^-}) changes.

Once the optimal values of γ and R are determined, the best predictions based on 3P_0 decay model are expected. In reference [20] H.G.Blundel *et al.* carried out a series of least squares fits of the model predictions to the decay widths of 28 of the best known meson decays, and the common oscillator

parameter R with a value of 2.5GeV^{-1} is suggested to be the optimal value. As for the factor γ , it was also fitted at the same time according to experimental data, giving a fitted value of 6.25 [20]. More detailed analysis of the input parameters in the 3P_0 model can be found in Ref. [20]. Thus, we adopt the SHO wave function with common R whose value is chosen to be 2.5GeV^{-1} . Correspondingly, the γ value is chosen to be 6.25 for the creation of u/d quark [20]. As for the strange quark pair($s\bar{s}$), its creation strength can be related by $\gamma_{s\bar{s}} = \gamma/\sqrt{3}$ [16]. As a simple test, we also calculate the decay ratio

TABLE II: The experimental values and numerical result based on the 3P_0 decay model of the ratio $\frac{\Gamma(D_2^*(2460) \rightarrow D^+\pi^-)}{\Gamma(D_2^*(2460) \rightarrow D^{*+}\pi^-)}$

BaBar [49]	CLEO [50]	CLEO [51]	ARGUS [52]	ZEUS [53]	$3P_0$
$1.47 \pm 0.03 \pm 0.16$	$2.2 \pm 0.7 \pm 0.6$	2.3 ± 0.8	$3.0 \pm 1.1 \pm 1.5$	$2.8 \pm 0.8_{-0.6}^{+0.5}$	2.29

$\frac{\Gamma(D_2^*(2460) \rightarrow D^+\pi^-)}{\Gamma(D_2^*(2460) \rightarrow D^{*+}\pi^-)}$ of $D_2^*(2460)$ meson with the above parameters. The corresponding experimental data from the BaBar [49], CLEO [50, 51], ARGUS [52], and ZEUS [53] collaborations are listed in TABLE II. The present calculation 2.29 based on the 3P_0 model is in agreement well with the average experimental value 2.35. Certainly, we can also predict the decay ratio $\frac{\Gamma(D_2^*(2460) \rightarrow D^+\pi^-)}{\Gamma(D_2^*(2460) \rightarrow D^{*+}\pi^-)}$ with some other methods such as the heavy-quark symmetry theory [54] and the heavy meson effective theory [55]. With the assumption that the transition is dominated by $\bar{u} \rightarrow \pi^- d$, the heavy-quark symmetry theory gave the expression of the decay ratio $r = \frac{2}{3}(\frac{p}{p^*})^5 = 2.44$, where $p = 507$ MeV and $p^* = 391$ MeV are the c.m. 3-momenta in the decays $D_2^{*0} \rightarrow D^+\pi^-$ and $D_2^{*0} \rightarrow D^{*+}\pi^-$, respectively. In reference [55], the heavy meson effective theory almost gave the same expression as it of the heavy-quark symmetry theory. Thus, our calculation is just a primary verification, which indicates that the 3P_0 model with the above parameters can reproduce the experimental data to some extent.

The numerical values of the decay widths and ratios of the charmed mesons $D_1^*(2680)$, $D_3^*(2760)$ and $D_2^*(3000)$ observed by the LHCb collaboration are presented in TABLE III-IV. It can be seen from TABLE III that the total width of $D_3^*(2760)$ is consistent well with the experimental data of LHCb collaboration, which indicates $D_3^*(2760)$ is most probably the $1D_2^{\frac{5}{2}}3^-$ meson. Besides the decay channel $D^+\pi^-$, the decay ratios in TABLE IV indicates that the other probable decay channels include $D^{*+}\pi^-$, $D^{*0}\pi^0$, $D_S^+K^-$, $D^{*0}\eta$, $D^0\eta$ and $D^+\rho$. As for $D_1^*(2680)$, the total width is predicted to be 208.91MeV which is about 21 MeV above the central value of the experimental data. Considering the total uncertainties of the experimental data, our result is also in agreement with it, which suggests that $D_1^*(2680)$ can be assigned as the $2S\frac{1}{2}1^-$ state. Besides $D^+\pi^-$, $D^{*+}\pi^-$, $D^0\pi^0$, $D^{*0}\eta$ and $D^{*0}\pi^0$ are also its dominant decay channels.

Experiments indicate $D_2^*(3000)$ is a 2^+ state charmed meson [1]. Thus, we study its decay behavior with the $1F\frac{5}{2}2^+$, $2P\frac{3}{2}2^+$, $2F\frac{5}{2}2^+$ and $3P\frac{3}{2}2^+$ assignments. As the candidate of $D_2^*(3000)$, the total width of $2F\frac{5}{2}2^+$ is predicted to be only 32.09MeV which is about 150MeV smaller than the central

TABLE III: The strong decay widths of $D_1^*(2680)$, $D_3^*(2760)$ and $D_2^*(3000)$ with possible assignments. If the corresponding decay channel is forbidden, we mark it by "-". All values in units of MeV.

	$D_1^*(2680)$	$D_3^*(2760)$	$D_2^*(3000)$			
	$2S\frac{1}{2}1^-$	$1D\frac{5}{2}3^-$	$1F\frac{5}{2}2^+$	$2P\frac{3}{2}2^+$	$2F\frac{5}{2}2^+$	$3P\frac{3}{2}2^+$
$D^{*+}\pi^-$	50.92	17.24	9.67	0.97	1.45	3.02
$D_S^{*+}K^-$	12.68	0.38	7.97	24.21	0.53	1.37
$D^{*0}\pi^0$	25.53	8.85	4.76	0.43	0.75	1.55
$D^{*0}\eta$	20.01	13.86	8.05	5.52	0.06	0.18
$D^{*0}\eta'$	-	-	7.75	16.58	0.87	2.10
$D^+\pi^-$	18.17	27.51	7.17	1.11	4.85	3.86
$D_S^+K^-$	22.68	2.52	10.35	11.17	0.08	0.09
$D^0\pi^0$	8.86	14.10	3.46	0.63	2.47	1.96
$D^0\eta$	16.37	5.13	7.88	0.37	1.13	1.04
$D^0\eta'$	-	-	15.82	9.84	0.46	0.33
$D^{*+}\rho$	-	-	15.70	100.10	0.41	7.23
$D_S^{*+}K^*$	-	-	3.27	34.87	1.09	5.74
$D^{*0}\rho$	-	-	7.85	50.10	0.19	3.51
$D^{*0}\omega$	-	-	7.87	50.11	0.23	3.82
$D^+\rho$	15.97	1.18	17.44	12.51	0.09	0.28
$D_S^+K^*$	-	-	8.01	28.72	1.31	3.39
$D^0\rho$	9.22	0.66	8.63	6.00	0.06	0.17
$D^0\omega$	6.28	0.51	8.82	6.49	0.04	0.12
$D(2420)\pi^0$	2.21	0.01	5.88	5.13	0.22	0.02
$D(2420)\eta$	-	-	9.31	1.49	0.58	0.50
$D(2430)\pi^0$	0.01	0	0.82	0.79	0.01	1.28
$D(2430)\eta$	-	-	1.49	1.99	1.32	0.69
$D_0^*(2400)\pi^0$	-	-	0	0	0	0
$D_0^*(2400)\eta$	-	-	0	0	0	0
$D_S(2460)K^-$	-	-	1.61	3.45	0.52	0.34
$D_S(2536)K^-$	-	-	10.14	1.39	2.78	1.47
$D_2^{*+}(2460)\pi^-$	-	0.65	16.73	39.69	5.93	10.46
$D_2^{*0}(2460)\pi^0$	-	0.32	8.38	19.88	2.97	5.24
$D_2^{*0}(2460)\eta$	-	4.49	5.22	11.82	1.69	2.81
$D_{s0}^{*+}(2317)K^-$	-	-	0	0	0	0
Total width	208.91	97.41	220.05	442.36	32.09	62.57

value of the experimental data. Thus, it can be completely excluded from the probable assignments. In addition, it can be seen from TABLE III that the width of $2P_{\frac{3}{2}}^+ 2^+$ is about 120MeV above the upper limit of the experimental data. Thus, $D_2^*(3000)$ is also impossible to be the $2P_{\frac{3}{2}}^+ 2^+$ state. In addition, if $D_2^*(3000)$ is $3P_{\frac{3}{2}}^+ 2^+$ state, its predicted cross section is 62.57MeV which is smaller about 123MeV than the central value of the experimental data. Although the calculated total width is just above the lower limit of the experimental data, its branching ratio of the $D^+\pi^-$ decay channel is very small. Thus, $3P_{\frac{3}{2}}^+ 2^+$ state is also less likely to be the assignment of $D_2^*(3000)$.

Although the predicted value of the total width of $1F_{\frac{5}{2}}^+ 2^+$ is somewhat bigger than the central value of experimental data, it is within the error range. This indicates $1F_{\frac{5}{2}}^+ 2^+$ is most likely to be the assignment of $D_2^*(3000)$. However, this determination needs to be further verified according to experiments in the future. We can see from Table IV that no decay channel show an obvious advantage over another, while the $D_2^*(3000)$ resonance is observed by the LHCb Collaboration in the $D^+\pi^-$ channel. One possible explanation about this behavior is that the production cross section of $D_2^*(3000)$ is so large that the fairly small branching ratio is still observable. If the decay ratios of different decay channels are measured in experiments in the future, this determination can be exactly verified. At present, we can temporarily assign $D_2^*(3000)$ charmed meson as the $1F_{\frac{5}{2}}^+ 2^+$ state, while $2F_{\frac{5}{2}}^+ 2^+$, $2P_{\frac{3}{2}}^+ 2^+$ and $3P_{\frac{3}{2}}^+ 2^+$ states can be excluded temporarily. Nevertheless, these decay predictions for the $2F_{\frac{5}{2}}^+ 2^+$, $2P_{\frac{3}{2}}^+ 2^+$ and $3P_{\frac{3}{2}}^+ 2^+$ states are valuable in further searches for the partners of $D_2^*(3000)$. For $2P_{\frac{3}{2}}^+ 2^+$ as an example, its decay ratios of $D^{*+}\rho$, $D^{*0}\rho$ and $D^{*0}\omega$ is much more obvious than the other decay modes, which can be used as a valuable judgement of this meson.

In reference [12], the decay behavior of $D_2^*(3000)$ was also analyzed using the 3P_0 decay model. The $3P_{\frac{3}{2}}^+ 2^+$ state was predicted as the most possible assignment of the $D_2^*(3000)$ in their work, while the assignment of the $2F_{\frac{5}{2}}^+ 2^+$ charmed meson could not be fully excluded. The primary difference between our analysis and theirs in reference [12] about the $D_2^*(3000)$ charmed meson is that they employed the SHO wave function with the effective scale parameter R [12], while we adopt the common value of the scale parameter R which was calculated by fitting the experimental data in reference [20]. Thus, the difference between the results in reference [12] and ours is mainly due to the influence of the input parameter R , which needs further confirmation by future experimental data from LHCb and forthcoming Belle II.

4 Conclusion

In this article, we carry out an analysis of the newly observed charmed mesons $D_1^*(2680)$, $D_3^*(2760)$ and $D_2^*(3000)$ reported by LHCb collaboration with the 3P_0 decay model. Our analysis supports $D_1^*(2680)$ and $D_3^*(2760)$ to be the $2S_{\frac{1}{2}}^- 1^-$ and $1D_{\frac{5}{2}}^+ 3^+$ assignments separately. In addition, the partial width and ratios are obtained, further shedding light on the nature of these two mesons. The total width predicted by the 3P_0 decay model supports the $1F_{\frac{5}{2}}^+ 2^+$ for the $D_2^*(3000)$ meson, which needs

further confirmation from the measured partial decay ratios. When investigating $D_2^*(3000)$, we have also analyzed the decay behavior of the $2P\frac{3}{2}2^+$, $2F\frac{5}{2}2^+$ and $2P\frac{3}{2}2^+$ states, which can be used as valuable judgements for the assignments of the newly observed charmed mesons in the future.

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TABLE IV: The decay ratios of partial decay width Γ_p/Γ_T of $D_1^*(2680)$, $D_3^*(2760)$ and $D_2^*(3000)$ with possible assignments.

	$D_1^*(2680)$	$D_3^*(2760)$	$D_2^*(3000)$			
	$2S\frac{1}{2}1^-$	$1D\frac{5}{2}3^-$	$1F\frac{5}{2}2^+$	$2P\frac{3}{2}2^+$	$2F\frac{5}{2}2^+$	$3P\frac{3}{2}2^+$
$D^{*+}\pi^-$	0.24	0.18	0.04	0.002	0.05	0.05
$D_S^{*+}K^-$	0.06	0.004	0.04	0.05	0.02	0.02
$D^{*0}\pi^0$	0.12	0.09	0.02	0.001	0.02	0.02
$D^{*0}\eta$	0.10	0.14	0.04	0.01	0.002	0.003
$D^{*0}\eta'$	-	-	0.04	0.04	0.03	0.03
$D^+\pi^-$	0.09	0.28	0.03	0.003	0.15	0.06
$D_S^+K^-$	0.11	0.03	0.05	0.03	0.003	0.001
$D^0\pi^0$	0.04	0.14	0.02	0.001	0.08	0.03
$D^0\eta$	0.08	0.05	0.04	0.0008	0.04	0.02
$D^0\eta'$	-	-	0.07	0.02	0.01	0.005
$D^{*+}\rho$	-	-	0.07	0.23	0.01	0.12
$D_S^{*+}K^*$	-	-	0.01	0.08	0.03	0.09
$D^{*0}\rho$	-	-	0.04	0.11	0.006	0.06
$D^{*0}\omega$	-	-	0.04	0.11	0.007	0.06
$D^+\rho$	0.08	0.01	0.08	0.03	0.003	0.004
$D_S^+K^*$	-	-	0.04	0.06	0.04	0.05
$D^0\rho$	0.04	0.007	0.04	0.01	0.002	0.003
$D^0\omega$	0.03	0.005	0.04	0.01	0.001	0.002
$D(2420)\pi^0$	0.01	0.0001	0.03	0.01	0.007	0.0003
$D(2420)\eta$	-	-	0.04	0.003	0.02	0.008
$D(2430)\pi^0$	0	0	0.004	0.002	0.0003	0.02
$D(2430)\eta$	-	-	0.007	0.005	0.04	0.01
$D_0^*(2400)\pi^0$	-	-	0	0	0	0
$D_0^*(2400)\eta$	-	-	0	0	0	0
$D_S(2460)K^-$	-	-	0.007	0.008	0.02	0.005
$D_S(2536)K^-$	-	-	0.05	0.003	0.09	0.02
$D_2^{*+}(2460)\pi^-$	-	0.007	0.08	0.08	0.18	0.17
$D_2^{*0}(2460)\pi^0$	-	0.003	0.04	0.04	0.09	0.08
$D_2^{*0}(2460)\eta$	-	0.05	0.02	0.03	0.05	0.04
$D_{s0}^{*+}(2317)K^-$	-	-	0	0	0	0